

LA-UR-21-31484

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Summer 2021 Co-op Report: X-Ray Scintillation Detector A Co-op Work Experience Report by Michael C. Solis Title:

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Intended for: Report

Issued: 2021-11-18



Summer 2021 Co-op Report: X-Ray Scintillation Detector

A Co-op Work Experience Report

by

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ENGR 3190
Summer 2021
August 5th, 2021

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ABSTRACT

The M-3 team was in need of a detector that could be used properly characterize their X-Ray machines. It can also be used to diagnose the X-ray in the case that problems arise before or during an experiment. They put me in charge of designing, ordering, and constructing said detector. After doing research, I found that scintillation-based detectors would be the best diagnostic tool for this purpose. It will allow the team to collect a full photon count of the X-ray pulse as well as provide spectroscopy functions with which we can view photon counts at different energy levels. This will also allow them to calculate an accurate dose given from the machine. Due to lead times, the crystal are still in manufacturing, thus the detector could not be completed. Although the designs and calculations needed to construct and operate the scintillator have been completed which is what I will be presenting in this document. Compared to the detectors being used before, my design offers a cheaper and far more efficient alternative.

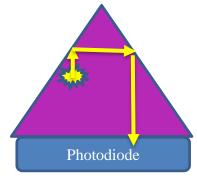
I. INTRODUCTION

X-rays are nothing new to modern science as its discovery originated with Wilhelm Roentgen accidently producing them back in 1895 where he "was quick to realize the importance of this mysterious new kind of ray he had discovered". Although the process of accurately creating and detecting them are still needing much improvement when it comes to utilizing them for imaging purposes. The objective of this project was to accurately characterize and diagnose the X-ray machines that we hold onsite if any strange occurrences were to occur. Before and during the experiment, the team also wanted a method to see the X-ray behavior so that we could take this into consideration when analyzing the data we received. After doing an extended amount of research of all common X-ray detectors, I decided that my design will utilize a scintillation crystal. Upon analysis, this design will give us an accurate total photon count given off by the X-ray source at its specific high energy level. With enough calibration, we will also be able to utilize the detector for spectroscopy which will allow us to get a photon count at different energy levels. This will give us all the required information to accurately calculate for dose as well. The technology of scintillator detectors are still making large advances to this day and they show many promising applications and advances over other X-ray detectors.

II. DESIGN

The way that a scintillator crystal works is by energy transformation. When an X-ray photon hits the crystal, it absorbs its energy and excites an electron. This is called an incident event. When the electron matrix shifts and returns to ground, it releases energy in the form of a photon and the crystal emits light in the UV- Near UV range. You can see this when putting a scintillation crystal into direct sunlight. The low cosmic radiation it receives allows the crystal to appear purple in color. This photon is then received by a photodiode which transforms the energy into a photocurrent. By analyzing the current outputted by the diode, we are able to get the number of photons hitting the photodiode. I will go more into depth with this in the next section.

There are numerous scintillator crystal compounds each with their own significant advantages. After researching the many materials that could be manufactured, I settled upon a LYSO:Ce (Cerium doped Lutetium Yttrium Silicate) compound. Some of the most notable specifications of LYSO crystals are their fast recovery time, useable emission wavelength, emission brightness,



and accuracy at high energy levels. I ordered for the crystal to be manufactured with a pyramid geometry with side lengths of 4 millimeters and a height of 2 millimeters. With reflective coatings on all sides except the base, this shape will allow for maximum photon detection by the photodiode. View the image to the left to get an idea of how the crystal shape "aims" its photon emissions. The photodiode chosen compliments the wavelength of light emitted by the scintillation crystal to provide maximum current and photon detection efficiency. I will provide actual number calculations in the next section. The photodiode will be

provided a constant voltage source via a power supply circuit that I designed. The circuit will also come with an RC filter that will reduce the amount of noise being input into the receiver

thus reducing the noise being output by the receiver. This will give us a clean output signal to work with and analyze. In the next section, I will address how we collect the data and how we calculate it to get the number of total photons

III. CALCULATIONS AND EFFICIENCY

We will start by using assumed variables to back calculate the voltage signal that we will be reading onto our diagnostic oscilloscope. Using this method, we can figure out how to forward calculate during the experiment with experimental data. During the experiment, we will be getting a voltage signal and working towards a photon count. To back calculate, we will be getting an estimated photon count of the machine in question and use it to find the voltage signal.

Starting off, our X-Ray machine gives off an estimated 5x10¹¹ photons / cm² at 100cm from the source over the time duration of its pulse of 80 nanoseconds. Dividing by 80 and converting the units into millimeters, we find that there are 6.25×10^7 photons / ns × mm². Knowing the surface area of our crystal, we can find the amount of photons hitting crystal which comes out to be 1×10^9 photons / ns. Over the period of 80ns this comes out to be 8×10^{10} photons hitting our scintillator crystal. Accounting for the attenuation of air and the aluminum housing around the crystal, we find that there is a 2.3% loss between the X-ray source and the surface of the crystal. Now, depending on the size and energy of X-rays, crystals can only absorb a certain amount of photons. In our case, it can only absorb 7% of them. Although this may seem like a low efficiency, compared to other detectors this is relatively high at this energy level. Now after accounting for this loss, we find that 5.47289x10⁹ photons are absorbed by the crystal. At our high energy levels, the crystal emits 64,000 photons per X-ray photon incident event. We find that 4.378313×10^{12} photons / ns are emitted by the crystal. Assuming there is little loss between the optical coupling and the refractive coatings, we can assume that all of these photons hit the photodiode which will give it a photon flux of $1.094578128 \times 10^{27}$ photons / s × m². The quantum efficiency, how many photons the diode will detect, at 420 nm, the average wavelength of crystal emission, is 29.56095% which tells us that 3.23926x10²⁶ photons are absorbed by the diode per second. Multiplying by the energy of each photon at 420 nm gives us the irradiance of 5.17708x10⁸ W / m² although since the duration is for only 80ns we find that 6.471 mW/m² is the irradiance from the crystal onto the diode. Looking at the chart given to us on the diode datasheet, we can see that this irradiance will give us a photocurrent 2.07 microamps. Now this current will going across a resistive load which will give is a voltage drop proportional to the current and the resistance. Knowing the voltage drop and the resistance of the load, we can find the photocurrent via ohms law. Calculating this process in reverse is how we find the photon count.

IV. CONCLUSION

X-ray scintillation detectors provide high efficiency and accurate photon counts of X-ray sources with high energy levels. The scintillator detector I have described above was designed to characterize and diagnose the X-ray machines we have on site at Los Alamos National Laboratory. In the future, I hope to utilize better crystal materials and to advance the technology of scintillator detectors. By utilizing faster photodiodes, faster scintillation crystals, and imaging

software, I hope to be able to make an X-ray camera that we can use to replace single-frame phosphors and will instead give us a frame-by-frame video of the experiment.

ACKNOWLEDGMENTS

I would like to acknowledge the M-3 team for their assistance during my project. I would also like to acknowledge my internship mentors Jaki Martinez and Mark Marr-Lyons for accepting me for this internship and constantly supporting me and providing me with any resources that were needed.

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